Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 63 (2013) 556 – 563

Procedia Engineering

www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2013

Characterizing of meshes for resistance welding of high temperature reinforced laminate thermoplastic (RLT)

I. González Requena*, A. Sanz Lobera, Luis Miguel Vega Fernández

Department of Aerospace Materials and Production. ETSI Aeronáuticos. Universidad Politécnica de Madrid, Plaza Cardenal Cisneros 3, 28040 Madrid, Spain

Abstract

The resistance welding is an excellent solution for the joint of pieces of compound material, considerably reducing the times and the costs of production with regard to other traditional methods. The analysis of the heating that takes place in the mesh will carry to optimize the process parameters and to assure a correct joint and properties in the whole area.

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion

Keywords: Welding, Resistance, Laminate, Thermoplastic, metallic heater insert

1. Introduction

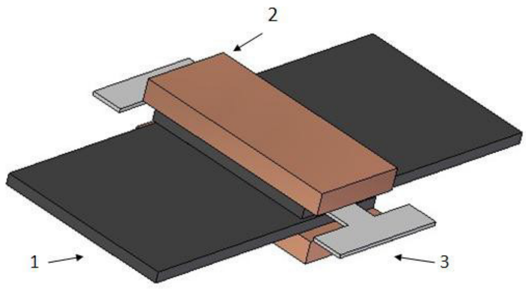
The resistance welding of strengthened laminated thermoplastics (LTR) is a good solution for the joining of this kind of materials Stravrov (2005). The smelting of the thermoplastic is achieved due to the heat dissipation by Joule's effect in a resistor (metallic mesh).

Resistance welding needs to have a metallic heater between the sides of both substrata, embedded in the welding when finished.

Figure 1 shows an example of a resistance welding system

* Corresponding author. Tel.: +34-913-366-330; fax: 34-913-366-334.
E-mail address: ignaciof.gonzalez@upm.es

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion
doi:10.1016/j.proeng.2013.08.256



1 Laminate
2 Insulation
3 Heater

Figure 1. Resistance welding system

This procedure can be applied to strengthened and non-strengthened thermoplastics. Special care must be taken when working with thermoplastic reinforced because the heating agent must be compatible with the matrix, due to high mechanical requirements of these materials.

One of the first thermoplastic used for the smelting of LTR was poly-etheretherketone Eveno (1988)

The weldings are normally elongated and its length depends on the available power of the source. For instance, in poly-etheretherketone's (PEEK) case, 340ºC must be reached to achieve a desired union Dubé (2007)

PEEK is a semi-crystalline thermoplastic with excellent mechanical and chemical properties that stay even at high temperatures. The Young modulus is 3.6 GPa and its traction resistance 90 to 100MPa. PEEK has a glass transition around 143ºC and melts approximately at 343ºC (662ºF). It is highly resistant to thermic degradation as well as to the attacks of organic and aquatic environments.

These properties and the advantages listed below make PEEK a reference thermoplastic for LTRs. In fact, it's the most used in the aeronautic industry.

The recommended working temperature range starts at -60ºC up to +250ºC. Some of the most significant advantages of PEEK Blog TdP (2011) are:

- High endurance to halogenated hydrocarbons, solvents, refrigerants, mineral oils, grease and transmission fluids.
- High endurance to abrasion and low coefficient of friction cut.
- Low humidity absorption, endures fluids, water, seawater, with low permeability.
- Completely recyclable.
- Resistant to a big range of chemical products at high temperatures and hostile environments
- Good stiffness and long term "creep" resistance.
- Good fatigue properties.
- Retains its properties when exposed to all kinds of temperatures.
- The main disadvantage is its high price.
- PEEK is approved by the biggest aeronautical companies.

When looking from manufacturing parts perspective, the disadvantage that it shows against other semi-crystalline thermoplastics of industrial use is the high melting temperature (343 ° C) requiring the use of special materials work as thermal and electrical insulators that have to withstand high temperatures.

Other thermoplastics widely used for welding are PEI (Polyether Imide) and PPS (Polyphenylene Sulfide) with lower processing temperatures as well as worse behaviors against temperature, corrosion and humidity Yuan (2001).

In this paper, three metallic meshes are studied: two steel meshes AISI 304, with 25 and 250 threads by inch and a bronze mesh with 165 threads by inch.

The objective of this paper is to choose the parameters that affect the union of thermoplastic matrix laminates, reinforced with carbon fiber. These parameters include the metal insert used, width, geometry (mesh type), the current running through the junction, the temporal variation law of the current, etc.

The aim is to get a fast and homogeneous weld of the thermoplastic, with the subsequent consolidation process, either in pneumatic or hydraulic press, so an optimal junction is reached, with reasonable time and costs.

2. Heating system.

For the characterization there have been realized tests of nude mesh and tests of complete heating system, also called heating agent. The warming agent is formed by the metallic mesh and an insulating material.

As insulating material, it is used fiberglass fabric with filler material, being used for this purpose a sheet of the same thermoplastic material (PEEK). Fiberglass fabric is not strictly necessary for welding performing, but it is used for avoiding the current losses that take place when, while is melting the sheet of thermoplastic material, the mesh touch the carbon fibre in the lamination, that is also conductive Dubé (2008)

2.1. Metallic Meshes.

As it has been previously said, there have been selected three types of different meshes two of them of stainless steel and another one of bronze (Figure 2), characterized by his diameter and his length as shown in Figure 3. Mesh characteristics are displayed in Table 1. M.A.M. (2013)

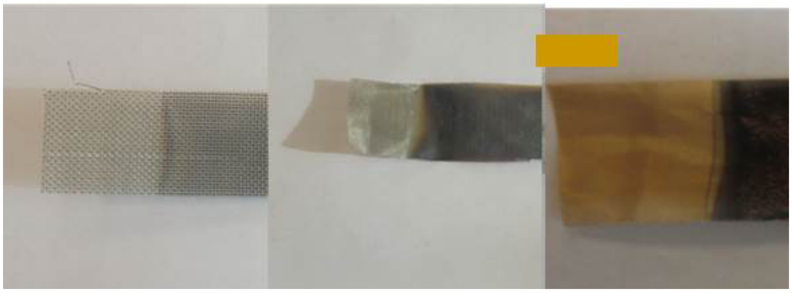


Figure 2. Mesh Types

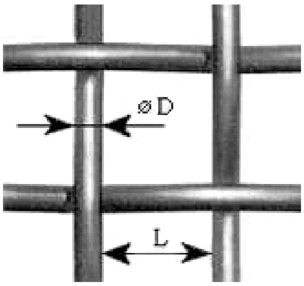


Figure 3. Mesh Parameters

Table 1. Mesh characteristics

Mesh Number	Material	Thread diameter (D) [mm]	Light (L) [mm]
25	AISI 304	0.36	0.75
250	AISI 304	0.035	0.08
160	Bronze	0. 053	0.46

The mesh with 25 threads per inch will provide less uniform temperature, but it will allow more crosslinkings between polymeric chains.

On the other hand, the mesh with 250 threads per inch will provide uniform temperature in its surfaces, but it is probable that such a small light does not allow so good adhesion between materials.

The bronze mesh has the same heating purpose than the steel mesh, but with a view to apply in future structures made by thermoplastics that need protection against lightning strike, since these structures has a bronze insert as conductive element.

Initially, a mesh of 28 threads per inch was tested, but it did not endure the necessary temperatures for the PEEK merger.

2.2. PEEK Sheet.

It is necessary to bear in mind that it will be needed extra thermoplastic material that fills the hollows of the mesh when the material melts. Now, it prevents the PEEK fill these voids and the subsequent loss of matrix in the end piece.

It is necessary to take into account the parameters D and L of the mesh to calculate the material to be used.

The thickness of thermoplastic film is given by the following expression:

$$t_R = 2 \cdot D \cdot \left(1 - \frac{\pi}{4} \left(\frac{D}{D+L} \right) \sqrt{1 + \left(\frac{D}{D+L} \right)^2} \right) \tag{1}$$

Therefore, thicknesses for every type of meshes would be the indicated ones in table 2.

Table 2. Thicknesses for different mesh types

Mesh	t_R (mm)
AISI 304-25	0,527
AISI 304-250	0,053
Bronze	0,146

The thickness of PEEK sheets is 120 microns.

Besides the mesh gap, it is necessary to take account of insulation fiberglass, the reason why a PEEK sheet was used in the configuration of the warming system to every side for the resistance of steel of 250 threads and for that of bronze and two sheets for every side for the resistance of steel of 25 threads.

Aside from the mesh hole, it is necessary to consider the fiberglass insulator so, in the heating system configuration, a PEEK sheet was used on each side for the steel of 250 threads resistance and for the bronze one, and two sheets on each side for the steel of 25 threads resistance.

Glass fiberThe configuration for each of them is shown in figure 4.

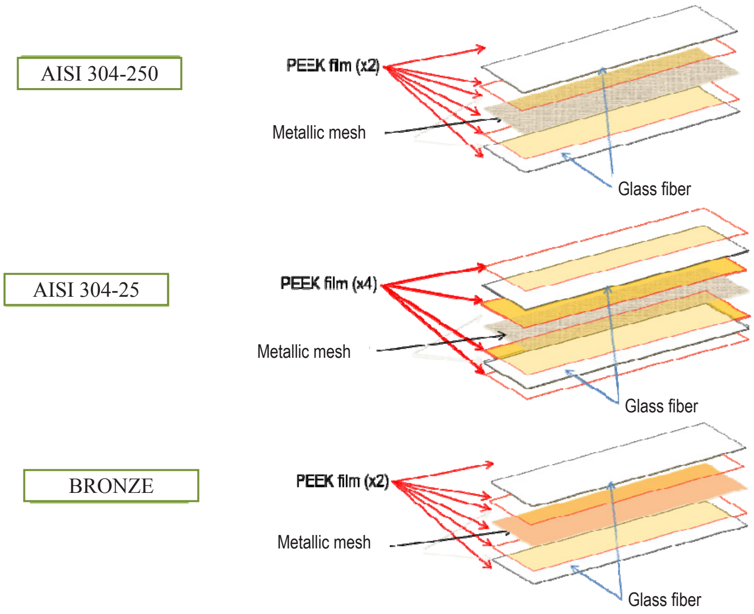


Figure 4. Configuration of heater inserts depending on the type of mesh.

3. Manufacturing heating inserts.

The heating inserts are made by a hot plated press.

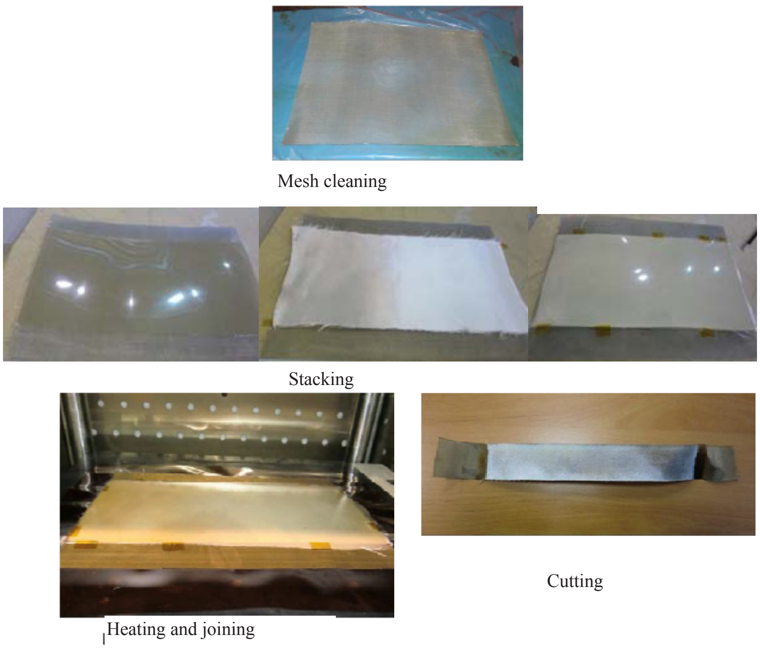


Figure 5. Steps for making a heating insert.

The steps to take are shown in Figure 5.

They are:
1. Cleaning of the mesh with dissolvent to prevent grease remains that will affect the part during heating.
2. Staking of each material following the outline shown in figure 4 for each type of mesh.
3. As auxiliary materials an “Upilex” tape is used to ease the joining of the different layers.
4. Heating and compaction in a hot plated press.
5. An “Upilex” plate is also used with a release agent to prevent the adherence of the insert to the press plates.
6. Preform cutting.

4. Characterizing of heating agents.

The test equipment is a power supply, brand " delta elektronika ",model SM45-70D, capable of providing a direct current of 45 V and 70 A. An ammeter clamp is arranged for the acquisition of information and it indicates us the current intensity in the mesh.

The instruments which are used for the temperature measure are an infrared pyrometer Raytek MX4, a thermographic camera FLIR SC2000 and a data logger. Figure 6

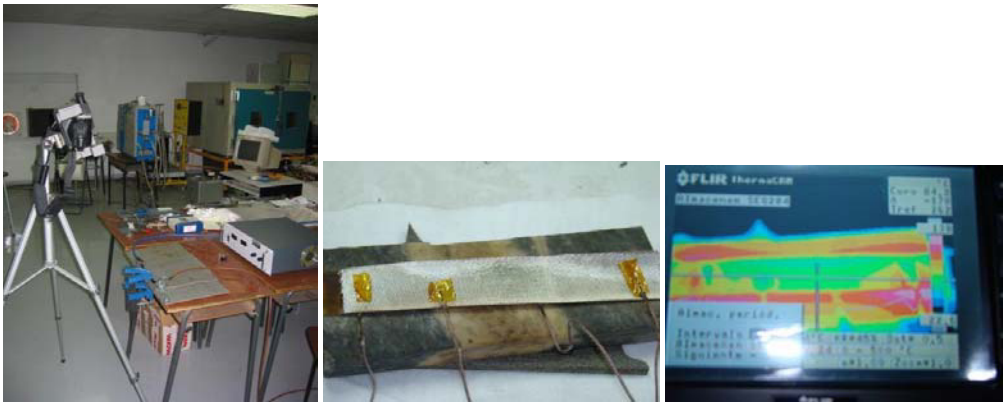


Figure 6. Test and Measure Systems

To make the experiments PEEK/GF specimens are taken, with 25x150 mm, with the configuration shown in Figure 3. Yousefpour (2004)

The different experiments consist in analyzing the heating of the specimens, changing the currents, until 340ºC is overcome, this temperature being the melting point of the thermoplastic.

With conducting clamps the mesh is secured to the voltage source and the thermocouples are fixed to the specimen.

The source is turned on and a staggered increase in the current is made to see how affects the heating of the mesh Dubé (2007)

The test was designed with a step of 5 amps per 100 seconds. However, this value was changed for some cases in which a temperature stabilization or other incidents happened. In these occasions, either the time between jumps was reduced, or the current increment was reduced.

In the following graphs (Figures 7 to 9) the variations of temperatures with the current increment can be seen, for the three types of heating agents tested.

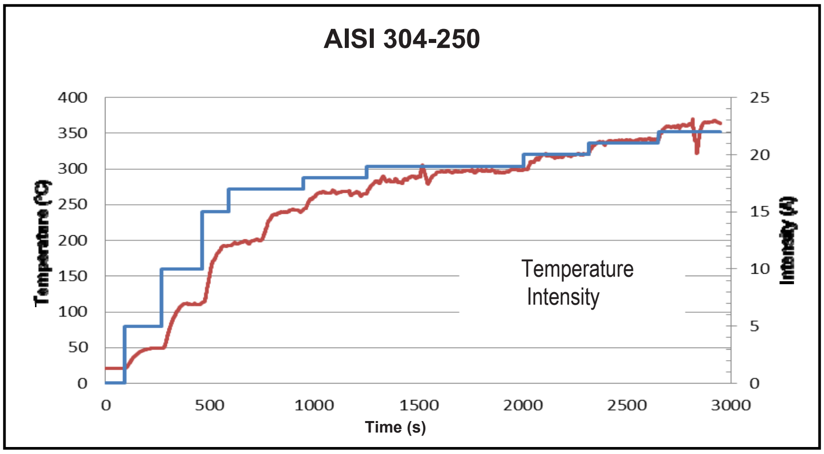


Figure 7. Temperature variation for the 250 threads steel mesh

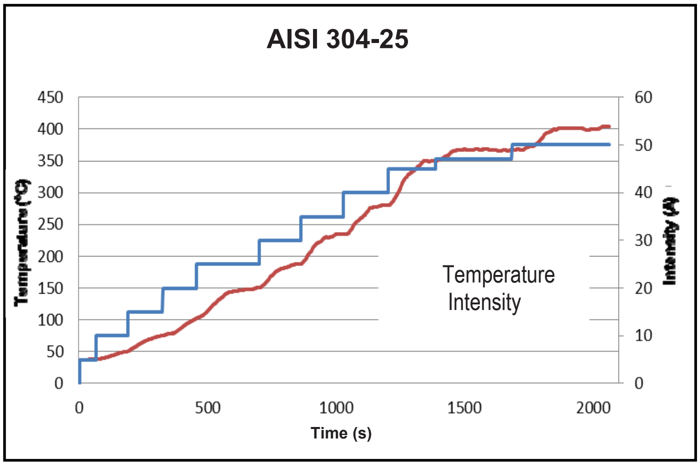


Figure 8. Temperature variation for the 25 threads steel mesh

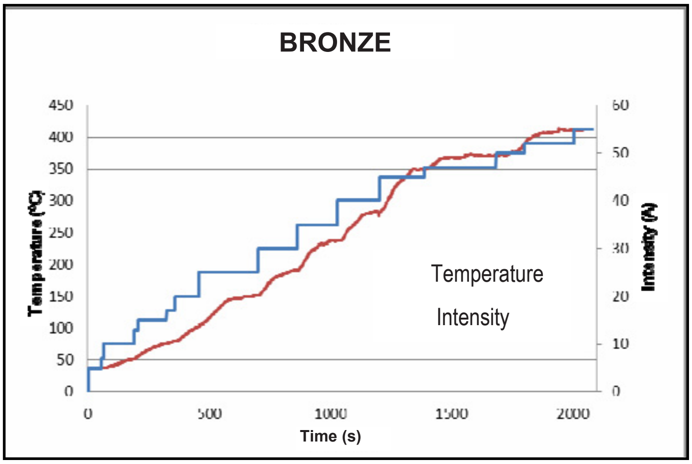


Figure 9. Temperature variation for the 160 threads bronze mesh

5. Analysis of Results.

Regarding the graphs above, a difference in the behavior of the agent with the highest heating steel mesh density can be seen, opposite to the other two ones. The temperature variation with the intensity of current is very much greater. This fact allows a more suitable process velocity when there is in use the heating agent of AISI 304-250.

Furthermore, the process temperature is obtained by currents of less than 25 A, while in the other two cases are necessary higher intensity values (more than 50 A) for the same temperature. This characteristic allows the weld of longer and wider elements using the AISI 304-250 mesh, since in the other two cases there would be reached the intensity limit that provides the power supply because of the increase of the warming zone section.

Another effect that can be appreciated is the resistivity variation with the temperature, since for equal intensity increases the variation of the temperature is faster. For the AISI 304-25 and bronze meshes the mentioned variation becomes important when it overcomes 275ºC due to the increase with intensity is slower. Nevertheless, the variation is faster for the AISI 304-250 mesh, so having approached the work temperature is necessary to be fitting the jumps to avoid resin degradation.

6. Conclusions.

In the beginning, it was thought that the most suitable mesh might be the bronze one for its application in structures resistant to beam.

On the other hand, the 25 threads mesh seemed to be suitable due to his minor density that would allow a better diffusion of the molten resin on both sides of the mesh.

Nevertheless, the best warming characteristics are the steel mesh of higher density ones. The warming speed is greater with minor intensities.

The weld process is optimized using as intensity value the maximum one to reach the necessary PEEK melting temperature. In the case of the 250 threads steel mesh, this value is 22A for the studied configuration.

The use of thermoplastic resins, instead of thermostable ones, would be benefited by the type of joint explained in this article, since it avoids the utilization of heavier elements as rivets.

The temperatures that are reached by the meshes allow a good joint between pieces, providing that an enough consolidation takes place to favour the self-adhesion mechanism between both faces.

As it was previously mentioned, the next step is to optimizing the pressure parameters.

References.

Blog TdP, 2011. http://tecnologiadelosplasticos.blogspot.com.es/2011/08/polieter-eter-cetona-peek.html

Dubé M., Huber P., Gallet J., Bersee H., Stavrov D., and Yousefpour A., 2007. Heating element optimisation in resistance welding of semi-crystalline and amorphous thermoplastic composites. CANCOM, Winnipeg, Canada.

Dubé M., Hubert P., Yousefpour A., Denault J., 2007. Resistance welding of thermoplastic composites skin/stringer, Composites Part A, 38, 2541-2552.

Dubé M., Hubert P., Yousefpour A., Denault J., 2008. Current leakage prevention in resistance welding of carbon fiber reinforced thermoplastics, Composites Science and Technology 68, 1579-1587

Eveno E.C. and Gillespie J.W. Jr., 1988. Resistance welding of graphite poly-etheretherketone composites: an experimental investigation. Journal of Thermoplastic Composite Materials, 1:322–338.

M.A.M., 2013. http://www.mallasmedina.com/telas.htm

Stavrov D. and Bersee, H.E.N., 2005. Resistance welding of thermoplastic composites-an overview, Composites Part A, 36, 39-54.

Yousefpour A., Simard M., Octeau M.A., Larmee M., and Hojjati M. 2004. Effects of mesh size on resistance welding of thermoplastic composites using metal mesh heating elements. In Proceedings of the 25th International SAMPE Europe Conference, pages 61–66.

Yuan Q., Hou M., Mai Y.W., and Ye L., 2001. Resistance welding of carbon fiber reinforced polyetherimide composite. Journal of Thermoplastic Composite Materials, 14:2–19.